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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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Patents ADP number *(if you know it)*
855/624001
855/632001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention
Device and method for 3Dimaging

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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-S110

Device and method for 3D imaging

Field of the Invention

The present invention is in the field of 3D scanning and 3D image reconstruction using structured light.

Background of the Invention

Structured light methods have been used to perform depth measurements in microscope images and to obtain 3D mask images of the external surfaces of microscopic and macroscopic objects. These methods are broadly based on either trigonometric considerations or an understanding of the frequency transfer characteristics of a lens. The latter methods involve the evaluation of patterned images, which are obtained by projecting substantially periodic structures by means of a grating onto an object. Commonly to achieve this, gratings are imaged in the object planes and displaced by integral fractions of the grating constant. An image is recorded for each position of the grating and the images are recombined. We choose to describe this physical method Structured Modulation Imaging (SMI).

WO-A-98/45745 relates to a microscopy imaging apparatus and associated imaging method and describes the use of structured light for generating an optically sectioned image of a specimen. In this method mask images are generated and only the in focus parts of the image

generated on the object by the grating are used for the image reconstruction.

In DE 19930816 A1 a similar SMI method is described in which surface information is determined by means of a projected structure with a periodic brightness, where this structure is displaced in steps of 1/n (where n is a whole number greater than 2) of the grating constant and the projection is captured by means of a 2D CCD camera. An algorithm is presented that also uses the defocused parts of the projected image for the reconstruction of the 3D image.

Both documents have in common that they relate to microscopy and describe methods in which the surface of an object is viewed from a single point of view. Both documents require the projection of three or more gratings, where each grating is shifted by a known fraction of the grating constant. The 3D information of the surface of one particular side of an object can then be obtained according to the methods described in the documents cited above. This means these methods relate to the imaging of surface structures of a specimen rather than the entire peripheral shape of an object. We call these surface structure images obtained from a single point of view 'mask' images in that they resemble face masks and do not contain 3D information from behind the front face of the object (reference is made to figure 1 where the difference between peripheral image and mask image is exemplified).

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There is a need to provide devices that are capable to not only reconstruct the 3D mask of a particular plane of an object but the three dimensional peripheral shape of the object. In addition there is a need to provide devices that capture the 3D peripheral shape of the object using a single projected grid.

There is also a need to provide devices for peripheral view images that are cheap to build and easy and quick to operate and furthermore easy and convenient to use. There is a need for a device that is capable to reconstruct the 3D peripheral view of an object with one single operational step, whereby an operational step is to be understood as placing the object in the scanning device, activate the device and obtain the 3D information of the object without any further intermediate steps to be carried out by the user.

The current invention provides an inexpensive, convenient and safe device and imaging method for reconstructing the 3D peripheral shape of an object using SMI. It has surprisingly been found that a device comprising a component suitable to create 'mask' type images by generating and recording only one "periodic pattern and a component enabling the creation of masks of at least two different sides of an object, enables the construction of a 3D image of an object in a simple and straightforward way. A device according to the invention is cheap to build and easy, quick and convenient to operate whereby the 3D peripheral view of an object can be reconstructed in a single operational step.

Summary of the invention

In one aspect the invention relates to a device for 3D imaging of the peripheral view of an object using structured modulation imaging said device comprising:

-one or more projecting system (S1) generating a periodic pattern on the object said system comprising one or more light source (L), one or more focussing means (F1), one or more patterning means (M1),

- one or more image recording system (S2) comprising a focussing means (F2) and one or more means (M2) of recording an image of the periodic pattern generated on the object,

wherein S1, S2 and the object are arranged relative to each other such that the periodic patterns can be generated and recorded for at least two different sides of the object,

In another aspect the invention relates to a method for 3D imaging of the peripheral view of an object using structured modulation imaging comprising

a) illuminating the object with a light source,

b) projecting a substantially periodic pattern on the object

c) recording an image of the periodic pattern on the object,

d) optionally recording the wide field image

wherein steps a-d are carried out for at least two different sides of the object and wherein the data obtained are analysed to reconstruct the 3D peripheral view of the object.

In yet another aspect the invention relates to a kit of parts comprising the device and one or more software package for analysing the recorded information and/or reconstructing the 3D peripheral view of the object.

Description of the figures

Figure 1 shows a representation of a 3D mask image (a) and a 3D peripheral view (b).

Figure 2 shows a schematic of the principle underlying SMI. L is a light source, M1 is a grating, F1 is a lens, f is a focal position and d is the distance between focal position and F1.
The physical principle that allows the present invention to obtain 3D surface distances from structured illumination requires a light source (L), a patterning means for generating a substantially periodic pattern of lighter and darker bands (M1) and a focusing means (F1). The pattern will be seen with maximum contrast between the dark and light bands at a given focal position (*f*). The contrast of the pattern falls off with a known response as a function of distance, d, away from *f* and the banding of the pattern will eventually become indistinct. The measured modulation depth of the pattern on the surface of the object gives a direct link to the distance that the surface patch is away from the focal position *f*.

Figure 3 shows schematic representations of preferred embodiments of the projecting system (S1). A detailed

description of the figure is given in the section describing preferred embodiments of S1.

Figures 4-6 are schematic representations of preferred embodiments of the device. A detailed description of the figures is provided in the section describing preferred embodiments of the device.

Detailed description of the invention

The invention relies on structured modulation imaging (SMI). This technique relates the intensity pattern (modulation contrast) of a periodic pattern projected on the surface of an object to its surface structure. If a substantially periodic grid of given frequency is projected via a lens onto a screen the observed intensity pattern on the screen has a modulation contrast that is at a maximum at the focal position of the lens. When the screen is moved away from the focal plane the observed modulation contrast on the screen diminishes. Reference is made to Figure 2 schematically showing the underlying principle. Figure 2 shows that the modulation contrast of the projected grating varies with distance from the focal plane. The relationship between modulation contrast and distance is a function of the lens properties, the spatial frequency of the periodic grid and wavelength of the light used. If an object is placed within the structured light field, surface features of that object that are in the focal plane show a high contrast of the projected grating while surface features away from the plane show a lower modulation contrast. The relationship between the distance from focal plane and the

observed modulation for a lens system is given in WO98/45745, which is incorporated by reference. In WO-A-98/45745 and DE 19930816, which are incorporated by reference, it is disclosed that if the grating is displaced by fractions of the grating constant and an image of its projection on the object is recorded for each position of the grating, the algorithms such as those described in WO-A-98/45745 and DE 19930816 A1 can be used to mathematically remove the pattern from the surface and hence reconstruct the 3D image of that surface. Not disclosed previously, we have now found that the displacement of the grating is not necessary in order to approximate the removal of the grating image from the composite image. Here the grating image is removed using correlation analysis over one or more cycles of the grating constant. Typically, the correlation analysis returns a depth measurement averaged over one or more cycles of the grating. As such the correlation analysis provides a good approximation for depth when the grating constant is smaller than structural features in the object. Optionally, and in addition to the composite image, the wide field image (image of the object alone) may also be used in the correlation analysis. The availability of the wide field image improves the approximation of depth measurement, particularly when the object contains surface detail associated with colour or grey scale rather than shape.

The device and method according to the invention allow the rapid 3D imaging of the peripheral shape of an object within one or more operational step. An operational step is herewith defined as placing the object on/in the device,

activate the device, obtain the 3D surface information (shape) of various different and/or all sides of that object.

In a preferred embodiment of the invention the information of the 3D peripheral view is obtained in a single operational step. This means according to a preferred embodiment a user can place the object in the device, activates the device and obtains the information of the peripheral shape and/or colour of the object without having to carry out any intermediate steps.

The functioning of the device according to the invention relies on two principles. The first principle (embodied in steps a-d of the method according to the invention) leads to the generation of a mask. The second principle relies on masks being generated for at least two different sides of the object. More particularly, the second principle relies on many narrow masks being generated about an entire circumference of the object. The information from the different masks is combined to reconstruct the peripheral view of the object.

Below, the components of the device according to the invention are listed.

An object according to the invention can be any object of suitable size to be placed in the device. Preferably the object is a macroscopic object, that means it can be seen with the naked-eye. The term "object" as used herein also comprises a multiplicity of objects.

The device according to the invention comprises one or more projecting systems (S1). Each projecting system comprises one or more of the following:
light source (L), focussing means (F1), patterning means (M1).

The object is illuminated by one or more light source (L). Any light source can be used, such as for example halogen lamps, electric light bulbs, light sources emitting coherent light, light sources emitting incoherent light, lasers or a collimated light source. Preferably the light source is a tube lamp.

A substantially periodic pattern is generated by M1 and projected on the surface of the object by F1.
A substantially periodic pattern is one in which there is a clearly dominant frequency component. The frequency components of a given spatial pattern can be estimated using standard computer means such as application of the Fast Fourier Transform algorithm.

The patterning means (M1) can be for example a grating. Any grating known in the art can be used to work the invention. The gratings may be linear, planar or spiral, one, two or three dimensional. An electronic spatial light modulator, using transmitted or reflected attenuation schemes may also be used. Alternatively, a periodic pattern may also be generated by interference of two or more suitably arranged coherent light beams, e.g. lasers.

Another way of generating a periodic pattern is by electronically modulating the intensity of the light source L, for example by using a collimated light source, in combination with a suitable focusing means (F1), for example a suitable mirror and a lens.

The periodic pattern generated by M1 can be one dimensional or two dimensional, stationary as well as movable. Preferably, M1 generates a periodic pattern having one dimensional local periodicity.

The position of M1 in relation to L, F1 and the object can be anywhere as long as the periodic pattern can be projected on a surface of the object.

The focussing means can be any suitable focussing means known in the art, such as for examples lenses, mirrors, screens or a combination thereof. The lens can for example be spherical or cylindrical. In case F1 comprises a mirror, the mirror can for example be curved or parabolic.

F1 can be positioned anywhere in relation to L, M1 and the object suitably to project the generated periodic pattern on the object.

In a preferred embodiment S1 projects a substantially one-dimensional (1D) periodic pattern on the object.

Preferred embodiments of S1 are shown in figure 3 to which reference is made.

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The preferred embodiment of S1 shown in figure 3a comprises a light source (L) illuminating a 2D grating (M1) and subsequently the object via a focusing means (F1).

The preferred embodiment represented in figure 3b shows the light source (L) illuminating the object via a 2D grating (M1) and focusing means (F1), and a screen D having a slit to produce a 1D patterned line of illumination. The angle of the grating with respect to the slit and/or the direction in which the grating is moved to provide two means for altering the spatial frequency of the 1D illumination pattern, thereby allowing altered modulation contrast characteristics for a fixed focusing means system. In the case where the grid is parallel to the slit, the slit should be sufficiently wide to permit one or more cycles of the grid to be projected.

Figure 3(c) represents another preferred embodiment of S1 comprising a tubular or essentially linear light source (L),

The preferred embodiment of S1 represented by figure 3(d) comprises a collimated light source (L) imaged via the focusing means (F1) comprising a cylindrical lens to produce a narrow line of illumination on the object. Where the grating is positioned parallel to the slit the width of the projection, should be at least one cycle of the grating constant.

The image of the periodic pattern, which is projected on the object, is recorded by one or more recording system S2.

S2 comprises at least one recording means M2 and at least one focussing means F2.

M2 can be any detector capable of receiving, digitizing and storing the information obtained in the image of the projected pattern. M2 can for example be a 1 or 2 D array of opto-electronically active picture elements such as are known in the imaging art, e.g. CCD, CMOS or CIS devices. Preferably, the image-recording system is suitable to receive and record also colour information. This allows not only to reconstruct the peripheral shape of the object but also its colour. Preferably the depth recording and colour recording are made separately. Preferably, M2 is a CCD device.

The imaging device can be operated as a continuous acquisition of the patterns such that each image represents an integration of the image over a small time period as the pattern is being moved. Alternatively, the images can be acquired after each movement. Images may overlap.

F2 can be any focusing means known in the art as for example lenses, mirrors, screens or a combination thereof. F2 may also be a mirror, preferably a parabolic mirror. F2 can for example be a lens of a CCD camera.

The following sections describe the grating removal processes.

Process 1: In order to mathematically remove the projected pattern from the surface and to apply correlation analysis algorithms without a separate wide field image one cycle of

the grating is required. Over one cycle of the grating all structural features of the object are assumed constant. Examples of structural features include, colour or grey scale, angle of inclination and depth. In this way one cycle of the grating yields a minimum, maximum and two mean intensities. Correlation analysis using these intensities yields an approximate depth measurement averaged over the grating cycle.

Process 2: In order to mathematically remove the projected pattern from the surface and to apply correlation analysis algorithms with a separate wide field image one cycle of the grating is required. Over one cycle of the grating some structural features are assumed constant, examples include angle of inclination and depth. In this way one cycle of the grating yields a minimum, maximum and two mean intensities. Correlation analysis using these intensities yields an approximate depth measurement averaged over the grating cycle.

Process 3: In order to mathematically remove the projected pattern from the surface and to apply algorithms such as described in WO-A-98/45745 and DE 19930816 A1 overlapping mask images are recorded in the following way:

A: Mask image 1 is recorded

B: S1 moves relative to the object by a known fraction of the grating constant.

C: Mask image n+1 is recorded

D: Steps B and C are repeated for n>2.

E: Grid removal algorithms are applied where the wide field overlaps in the n images.

Movement of S1 relative to the object can be carried out either by moving the object or by moving S1.

It is noted that DE 19930816 A1 refers to displacements by integral fractions of the grating constant. It has been found that in the device according to the invention, the displacements can be carried out at any fractions of the grating constant.

It is further noted that n according to the above in principle only need to be equal to two and not greater than two. If n=2 the reconstruction of the image is approximate. In order to obtain an exact reconstruction we require n>2.

The device may further comprise a turntable on which the object is placed. The turntable may be moved electronically, mechanically, stepwise or continuously. The turntable may be transparent allowing also the side on which the object rests to be scanned by the device.

The turntable may be rotated between 0 and 360 degrees within one or more planes.

S1 and S2 are arranged such that no triangulation is required in the image analysis process. This may be achieved by collocating S1 and S2. This may also be achieved with the aid of mirrors.

In order to obtain the peripheral view of an object, masks from at least two different sides of the object need to be constructed. In order to achieve this in a rapid and convenient way S1 and S2 are arranged relative to the object so that masks can be constructed of at least two

different sides of the object. Preferably many narrow masks are measured, this can be achieved in a number of ways.

The device may for example comprise a turntable on which the object is placed. The turntable may be rotated stepwise or continuously, mechanically or electronically in relation to S1 and S2. In this embodiment the device preferably comprises only one S1 and one S2, which are at fixed positions. By moving the turntable between 0 and 360 degrees (not including 360 degrees) the object can be imaged peripherally.

Alternatively, S1 and S2 may be in a fixed position relative to each other but capable to be moved around and/or over an object either continuously or stepwise, mechanically or electronically. In this embodiment, the object is preferably at a fixed position, although it is also possible to include a turntable in this device.

In another embodiment according to the invention the device comprises a plurality of projecting systems and recording systems at various positions, each combination of S1 and S2 facing different sides of the object. The systems may be at fixed positions or movable.

According to another embodiment, the device is configured as to comprise a combination of the above.

In order to image also the side on which the object rests optionally a transparent turntable is used or a second operational step is introduced wherein the object is turned

such that it rests on a different side and the scanning process is repeated.

In order to reconstruct the 3D information of one view of the object (to generate a mask) algorithms such as described in DE 19930816 A1 or correlation analysis is applied for which the device preferably comprises suitable software. Preferably, the device is also provided with suitable software to recombine the masks for reconstructing the peripheral shape of the object. Furthermore, the device is optionally provided with means to display the generated peripheral view. The device may also be used as computer peripheral and is then provided with a means to record and store the information such that the information and/or the peripheral view can be processed, generated and displayed on a separate computer. The invention therefore also relates to a kit of parts comprising the device and a software package for analysing processing and displaying the surface information.

In another aspect the invention provides a method of 3D imaging of the peripheral view of an object. Parts of the method have already been illustrated during the description of the device. The method according to the invention comprises

a) illuminating the object with a light source,
b) projecting a substantially periodic pattern on the object
c) recording an image of the periodic pattern on the object,
d) optionally recording the wide field image

wherein steps a-d are carried out for at least two different sides of the object and wherein the data obtained are analysed to reconstruct the 3D peripheral view of the object.

This is further demonstrated by preferred embodiments, which are not to be understood as limiting.

In one embodiment steps a-d are carried out for one particular view of the object. Steps a-d are then repeated for other views of the object and the combined data is analysed for the reconstruction of the peripheral view.

In another embodiment a plurality of systems S1 and S2 record images of periodic patterns that have been generated at different sides of the object. After these images have been recorded the systems are moved relative to the object and the wide field images are recorded.

Prior to use the device can be calibrated. Calibration can be carried out once and the device is set up or calibration can be carried prior to every single use.

Calibration of the device can for example be provided as follows.

A calibration means of known dimension is inserted into the device and the 3D scanning process is carried out. The observed values of modulation ratio for each surface patch are then cross-correlated with the known distances that exist for each surface patch. The results of the correlation are stored in a look up table so that during normal operation an observed modulation ratio value is transformed into distance before further data processing.

Alternatively all data processing can be carried out in modulation ratio values and after processing transformed into real distances.

In a preferred embodiment of the invention a calibration figure is inserted on, above or below a turntable and fixed so that on rotation of the turntable the figure rotates. The observed values of modulation ratio for each surface patch are then cross-correlated with the known distances that exist for each surface patch on the calibration figure. The results of the correlation are stored in a look up table so that after a complete revolution of the turntable the observed modulation ratio values can be transformed into distances before further data processing. By this arrangement each full 3D scan is self calibrated without any further calibration steps.

The invention is now further described by a number of preferred embodiments.

Embodiments of the Device

Embodiment I

A schematic of a preferred embodiment of the device is shown in figure 4.

In this embodiment of the invention S1 is described in figure 3d, i.e. comprising a tubular lamp as a light source (L), a parallel grating (M1), a screen with a slit parallel to the long axis of the light source (D) and a cylindrical lens (F1). The device comprises a turntable on which the

object can be placed (indicated by bent arrow). S2 is a CCD camera.

A preferred way of operating this device is as follows:

The object is illuminated with one or more cycles of the periodic pattern, and recorded. The object is then rotated by a fraction of one cycle, one cycle, or more than one cycle of the periodic pattern. This process is repeated until the object has been circumnavigated once. The data of the different masks are combined for reconstruction of the peripheral view of the object. Optionally the wide field image without grating is recorded by the same process.

Embodiment II

This embodiment is similar to embodiment I. In this embodiment S2, a CCD camera, is attached to S1 which is the preferred embodiment shown in figure 3d, and both S1 and S2 are moved around and/or over the object thus obtaining surface information of several sides of the object. This embodiment is represented in figure 5.

Embodiment III

This embodiment comprises three projecting and recording systems (S1 and S2) arranged at different positions in the device so that each combination of projecting and recording system faces a different side of the object.

A representation of this embodiment is shown in figure 6.

Claims

1. A device for 3D imaging of the peripheral view of an object using structured modulation imaging comprising: -one or more projecting system (S1) generating a periodic pattern on the object, said system comprising one or more light source (L), one or more focussing means (F1), one or more patterning means (M1), - one or more image recording system (S2) comprising a focussing means (F2) and one or more means (M2) of recording an image of the periodic pattern generated on the object, wherein S1, S2 and the object are arranged relative to each other such that the periodic patterns can be generated and recorded for at least two different sides of the object,

2. A device according to claim 1 wherein the object is a macroscopic object.

3. A device according to any preceding claim comprising software for analysing the recorded information and/or reconstructing the 3D image of the object.

4. A device according to any preceding claim wherein M2 is a CCD camera.

5. A device according to claim 6 wherein F2 is a lens of the CCD camera

6. A device according to any preceding claim further comprising a turntable on which the object can be placed.

7. A device according to any preceding claim comprising a plurality of S1 and S2 in a fixed spatial arrangement each combination of S1 and S2 facing different sides of the object.

8. A device according to any of claim 1-6 comprising one S1 and one S2 in a fixed spatial position and a turntable which can be turned in relation to S1 and S2.

9. A device according to any of claim 1-6 wherein S1 and S2 are fixed in relation to each other and wherein S1 and S2 can be moved around and/or over the object.

10. A device according to any preceding claim wherein the periodic pattern generated has local one dimensional periodicity.

11. A method for 3D imaging of the peripheral view of an object using structured modulation imaging comprising
    a) illuminating the object with a light source,
    b) projecting a substantially periodic pattern on the object
    c) recording an image of the periodic pattern on the object,
    d) optionally recording the wide field image without the periodic pattern

characterised in that steps a-d are carried out for at least two different sides of the object and wherein the data obtained are analysed to reconstruct the 3D peripheral view of the object.

12. A method according to claim 11 wherein the object is a macroscopic object.

13. A kit of parts comprising a device according to claim 1 and one or more software package for analysing the recorded information and/or reconstructing the 3D peripheral view of the object.

Abstract

A method and device are described for 3D imaging of objects whereby an object is illuminated by a light source and a periodic pattern is generated on the object. The image is recorded and analysed to remove the spatial pattern from the image~~s~~. This is carried out for different sides of the object to obtain the full 3D image of the object.

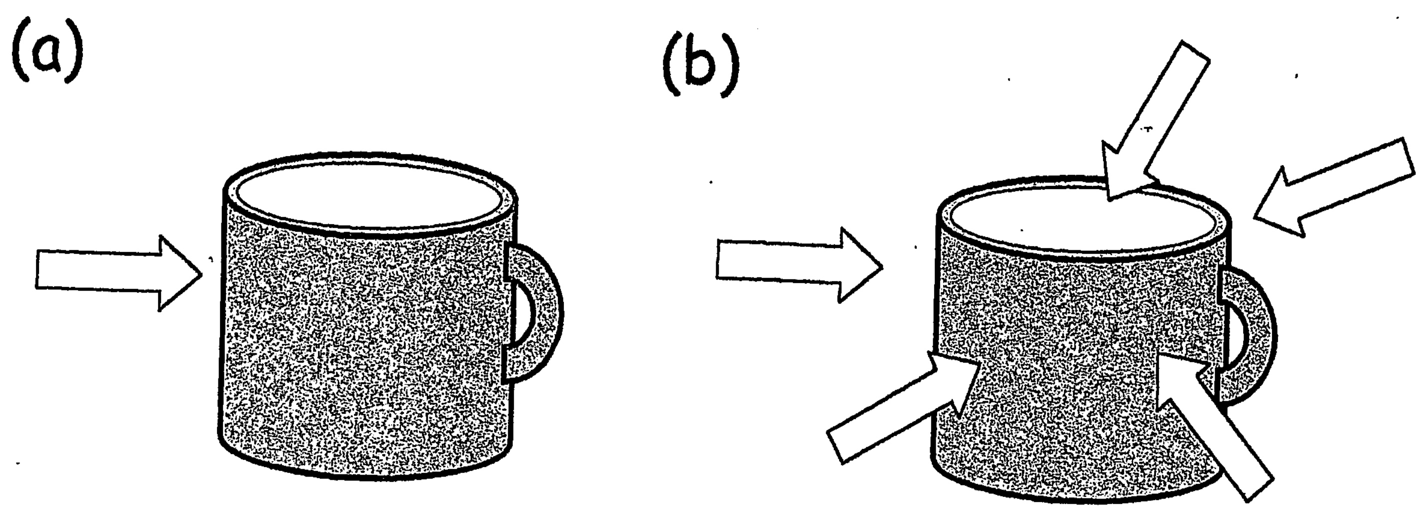

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Figure 1

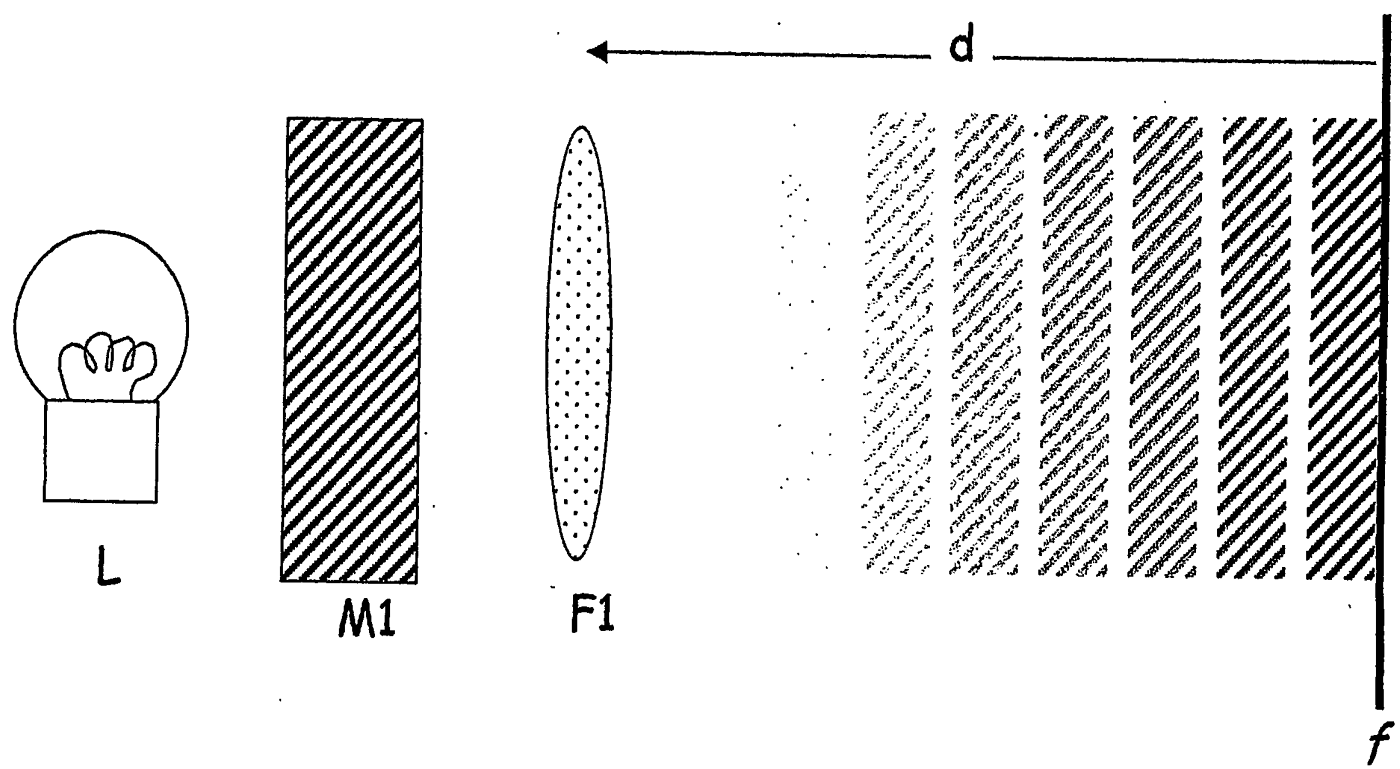

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Figure 2

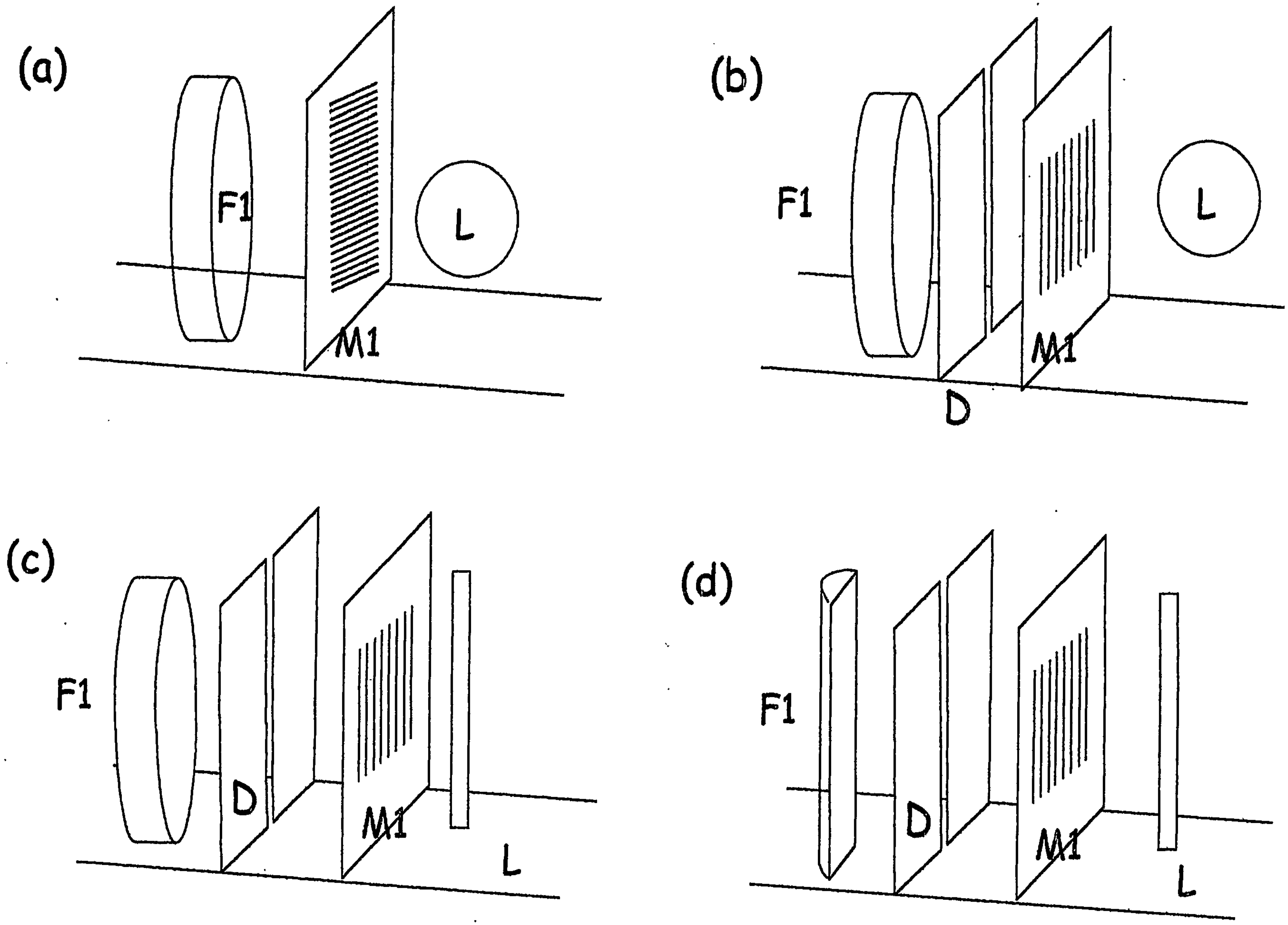
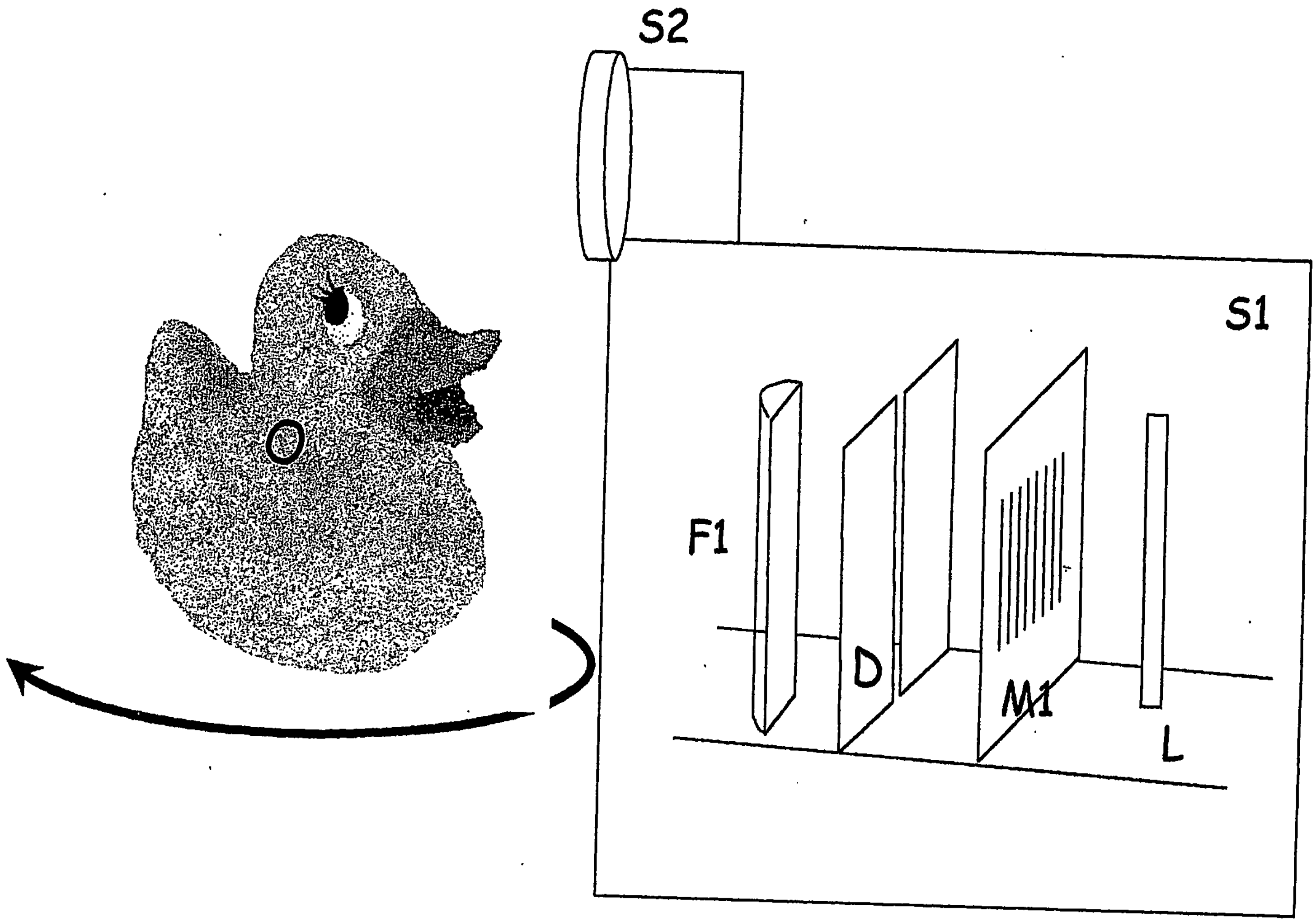


Figure 3



ss1102

Figure 4

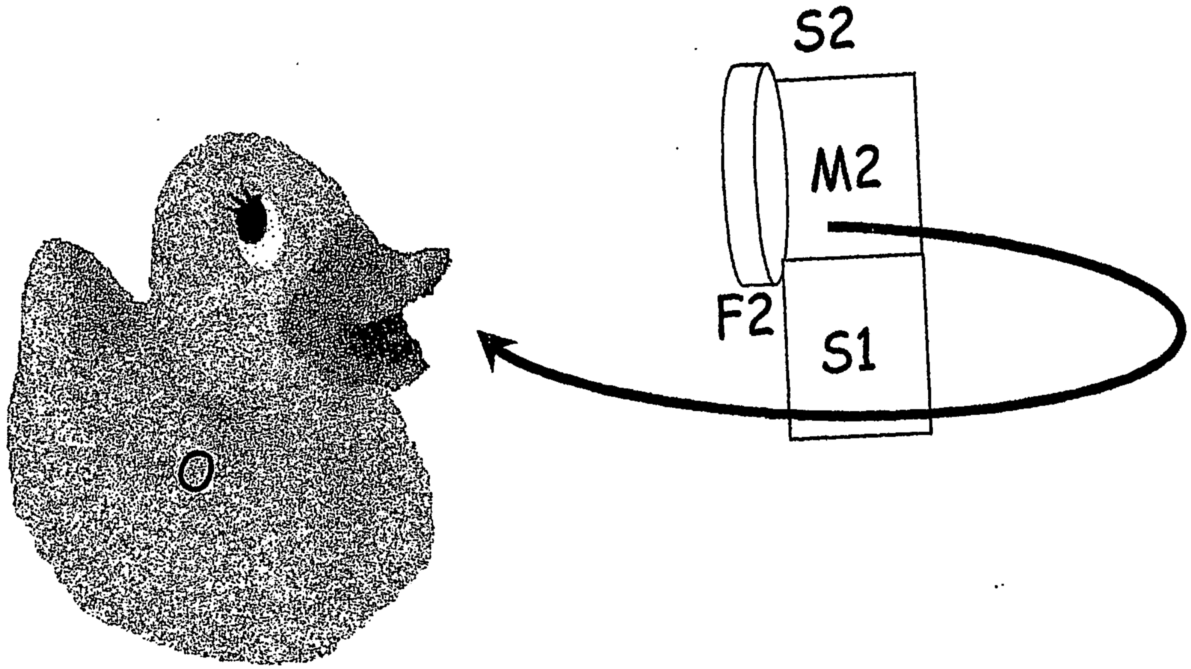


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Figure 5

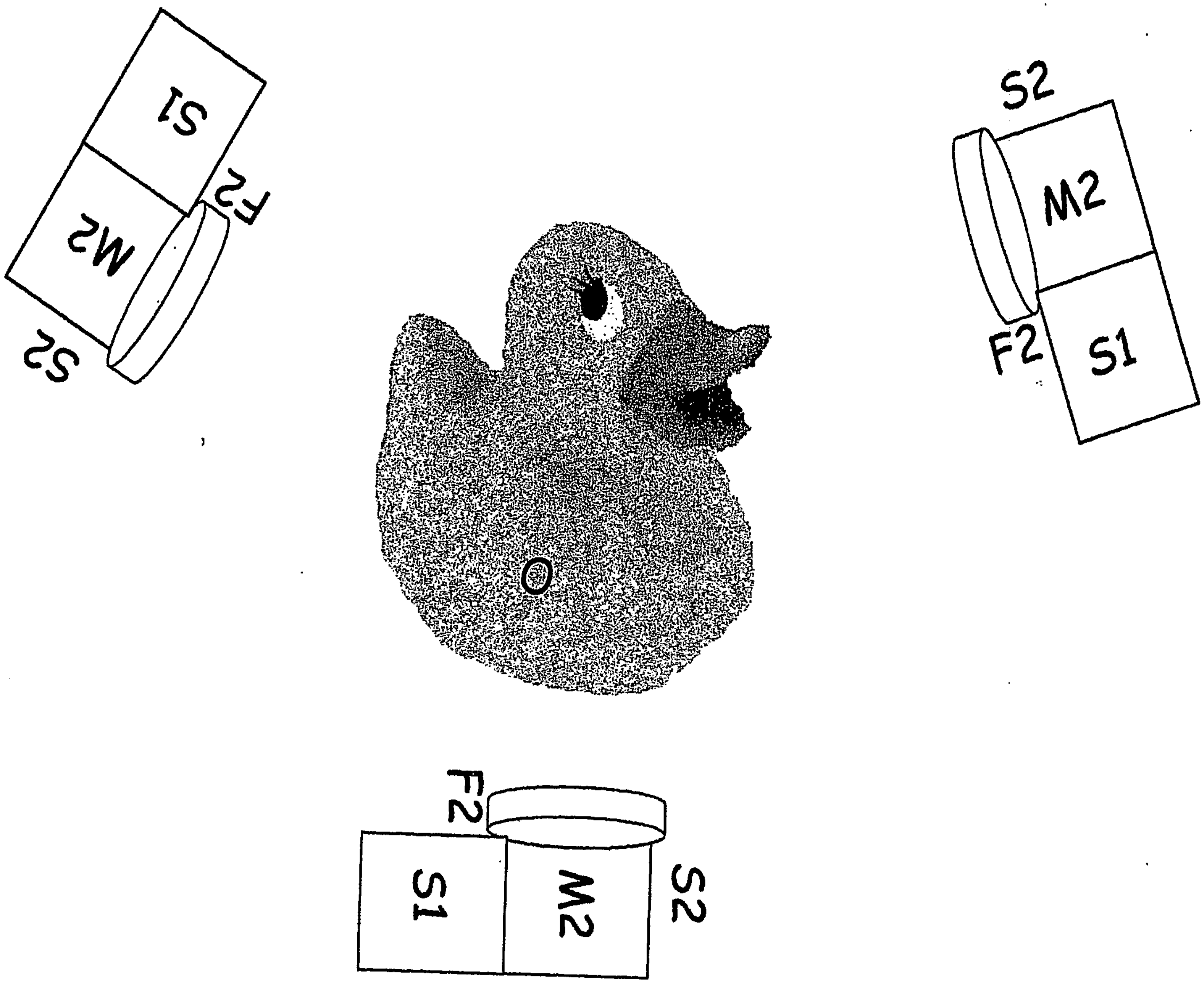

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Figure 6

PCT Application
PCT/GB2004/000311